Appendix 15

Radionuclide Production in Soil at NSLS

Introduction

The purpose of this appendix is to estimate the potential for soil activation resulting from operation of the NSLS injection systems and storage rings. It should be noted that any soil activation associated with NSLS lies fully beneath the footprint of the building. Therefore, there is no potential for rainwater leaching tritium or sodium – 22 from the soil into the aquifer. Nonetheless, it is worthwhile to know if any significant soil activation is created in the soil below the facility as the result of NSLS operations.

Neutron Source Terms

There is no exposure to soil of the NSLS electron beams or forward directed bremsstrahlung beams. Therefore, the principal source of radionuclide production in soil is associated with electron beam losses during operation that produce neutrons of sufficient energy to create spallation products in the atomic constituents of soil. The principal loss points were identified in section 4.12 of the SAD. For purposes of this calculation, we will use the highest power loss point created by stopping the extracted Booster beam in on of the injection stoppers.

Induced activity in the soil can only come from particles emitted at 90^0 to the interaction point as there are no points where forward directed secondary radiation can interact with soil. Only activation produced by high-energy neutrons will be considered.

We will assume a beam of 1×10^{10} e/s at 1 GeV. The power (P) in the stopping beam is

$$P = I\,V = 1 \times 10^{10} \text{ e/s} \times 1 \text{ Amp}/6.25 \times 10^{18} \text{ e/s} \times 1 \times 10^{9} \text{ V} = 1.6 \text{ watts} \qquad (1)$$

From Sullivan[1] (p. 80), the dose equivalent for high-energy neutron (HEN) (E> 100 MeV) component at 90^o from electrons stopping in a thick iron target can be written as:

$$H(HEN) = 36 \text{ Rem/hr/KW at 1 m} \qquad (2)$$

Or

$$H(HEN) = 36 \text{ Rem/hr/KW} \times 1.6 \times 10^{-3} \text{ kW} = 58 \text{ mRem/hr} \qquad (3)$$

Using figure 3.2 (p. 78) from Sullivan[1], this value is reduced by 1/3 since the energy of this beam is 1 GeV, or

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[1] **A Guide to Radiation and Radioactivity near High Energy Particle Accelerators**; A.H. Sullivan, Nuclear Technology Publishing; 1992

$$H(HEN) = 1/3 \text{ x } 58 \text{ mRem/hr at 1 m} = 19.3 \text{ mRem/hr @ 1 m} \quad (4)$$

For neutron with E > 100 MeV, the fluence to dose equivalent conversion factor is:

$$5.6 \text{ n/cm}^2\text{/s} = 1 \text{ mRem/hr} \quad (5)$$

Therefore the HEN fluence Φ

$$\Phi(HEN) = 19.3 \text{ mRem/hr x } 5.6 \text{ n/cm}^2\text{/s per mRem/hr} = 116 \text{ n/cm}^2\text{/s @ 1 m} \quad (6)$$

We can now calculate the activity created in the soil below the NSLS stopper.

Tritium Production

The Booster beam line is 90 cm above the floor and the floor is 20 cm of concrete. The attenuation length in concrete for neutrons in this energy range is 100 g/cm^2, and the distance from the stop to the soil is 1.1 meter. Therefore, the high-energy neutron (HEN) fluence Φ reaching the soil is:

$$\Phi = 116\,(1/1.1)^2 \text{ x } e^{-8" \text{ x } 2.54 \text{ x } 2.35 / 100} = 59.5 \text{ n/cm}^2\text{-s} \quad (7)$$

The tritium production rate A in units of dis/s/g produced by an irradiation ot time t can be calculated from[2]:

$$A = N\sigma\Phi(1 - e^{-\lambda t}) \quad (8)$$

where

λ is the radioactive decay constant for tritium ($\lambda = 0.056 \text{ yr}^{-1}$), and σ is the cross section for tritium production from spallation in oxygen and silicon and is taken as 10 millibarns (mb)[3].

N is the number of target atoms per gram in soil (SiO_2) with density 1.6 g/cc:

$$N = 6.02 \text{ x } 10^{23} \text{ molecules per gram-mole x 3 atoms/molecule} \div 60 \text{ g/ g-mole} \quad (9)$$

$$N = 3 \text{ x } 10^{22} \text{ atoms / g} \quad (10)$$

Assuming an irradiation time 300 hours per year[4], the fluence Φ' averaged over one year

[2] "Radiation Physics for Personnel and Environmental Protection", Course Proceedings by J. Donald Cossairt, U.S Particle Accelerator School, Jan. 1993.
[3] W.R. Nelson, A. Fasso, R. Sit, and S.N. Witebsky - "Estimate of Tritium Production in GroundWater near SLC Beam Dumps" Feb. 1998; SLAC RP Note 98/2R
[4] The ring injection systems operate only during fill cycles for the storage ring, typically 10 minutes per fill. Total time per 24-hour period for both rings is approximately 90 minutes and we assume 200 days per year.

$$\Phi' = 59.5 \text{ n/cm}^2\text{-s x [300 hours} \div \text{24 hours/day x 365 days/year]} = 2.04 \text{ n/cm}^2\text{-s} \quad (11)$$

Therefore the tritium production rate (A) in disintegrations per second per gram of soil from 300 hours of operation in one year is

$$A(1 \text{ yr}) = 3 \times 10^{22} \times 10 \times 10^{-27} \times 2.04 \times (1 - e^{-0.056 \times 1}) \quad (12)$$

$$A(1 \text{ yr}) = 3.33 \times 10^{-5} \text{ d/s/g} = 9 \times 10^{-4} \text{ pCi/g } H^3 \text{ in soil} \quad (13)$$

$$A(1 \text{ yr}) = 9 \times 10^{-4} \text{ pCi/g } H^3 \times 1.6 \text{ g/cc} = 1.4 \times 10^{-3} \text{ pCi/cc } H^3 \text{ in soil} \quad (14)$$

The Accelerator Subject Area provides a methodology for determining the acceptability of induced activity in soil. For tritium, the model assumes that tritium in soil will result in soil water leachate that is 1.1 times the soil water concentration

Therefore C (H^3 soil water leachate) is

$$C(H^3 \text{ soil water leachate}) = 1.4 \times 10^{-3} \text{ pCi/cc} \times 1.1 = 1.58 \times 10^{-3} \text{ pCi/cc} = 1.58 \text{ pCi/l} \quad (15)$$

The Subject Area establishes that calculated H^3 leachate values in excess of 1000 pCi/l would require further safeguards and monitoring. Therefore, no corrective actions are required for this level of tritium production.

Na^{22} Production

The Subject Area also requires that Na^{22} production be calculated. Cross-sections for Na^{22} production are not available; therefore the measurements and calculations from SLAC RP-2000-07 [5] are used to estimate Na^{22} productions rates. From that report , it can be estimated that

$$A_{Sat.}(Na^{22}) = 1/2\, A_{Sat.}(H^3) \quad (16)$$

From equation (12) above, $A_{Sat.}(H^3)$ in the soil beneath the NSLS can be calculated to be

$$A_{Sat.}(H^3) = 1.6 \times 10^{-2} \text{ pCi/g} \quad (17)$$

Therefore ,

$$A_{Sat.}(Na^{22}) = 8 \times 10^{-3} \text{ pCi/g} \quad (18)$$

We can then calculate the production in one year to be:

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[5] James Liu and Sayed Rokni - "Analytical Method in Estimating the Induced radioactivity in Soil around High energy Accelerators" Oct, 2000; SLAC RP Note 2000-07

$$A_{1\,yr.}(Na^{22}) = A_{Sat.}(Na^{22}) \times (1 - e^{-0.266 \times 1}) \quad (19)$$

$$A_{1\,yr.}(Na^{22}) = 8 \times 10^{-3}\ pCi/g \times (1 - 0.766) \quad (20)$$

$$A_{1\,yr.}(Na^{22}) = 1.87 \times 10^{-3}\ pCi/g = 3 \times 10^{-3}\ pCi/cc \quad (21)$$

The Subject Area prescribes that we assume that 7.5% of the sodium induced in soil becomes leachable and that a concentration factor of 1.1 be applied to the leachable fraction. Using these values, the concentration in soil water leachate for Na^{22} is

$$C(\text{soil water leachate}) = 3 \times 10^{-3}\ pCi/cc \times .075 \times 1.1 = 0.25 \times 10^{-3}\ pCi/cc = 0.25\ pCi/l \quad (22)$$

The Subject Area establishes that calculated Na^{22} leachate values in excess of 20 pCi/l would require further safeguards and monitoring. Therefore, no corrective actions are required for this level of Na^{22} production.

Conclusion

Tritium and sodium-22 production in soil from operation of NSLS beam dumps do not require any additional engineering controls or monitoring.